Computational Reconfigurable Imaging Spectrometer (CRISP)

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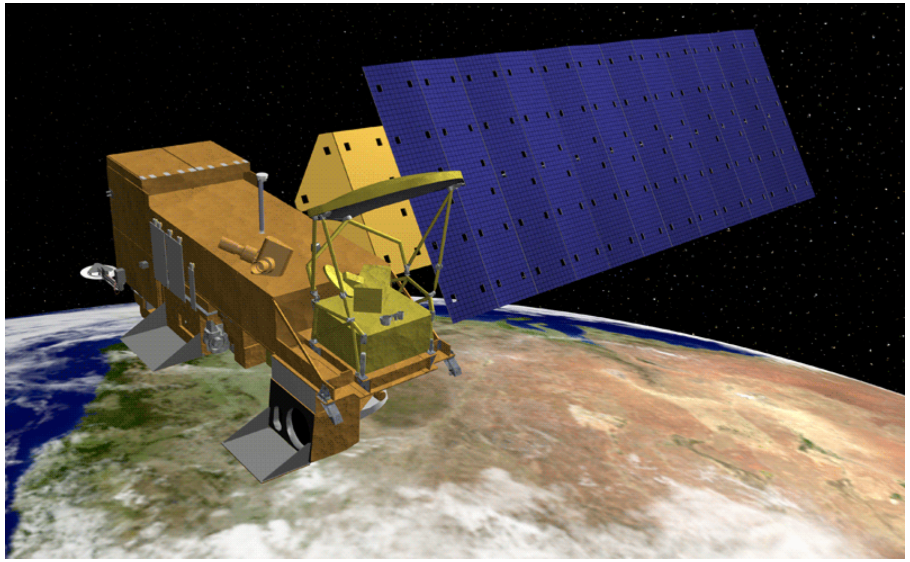
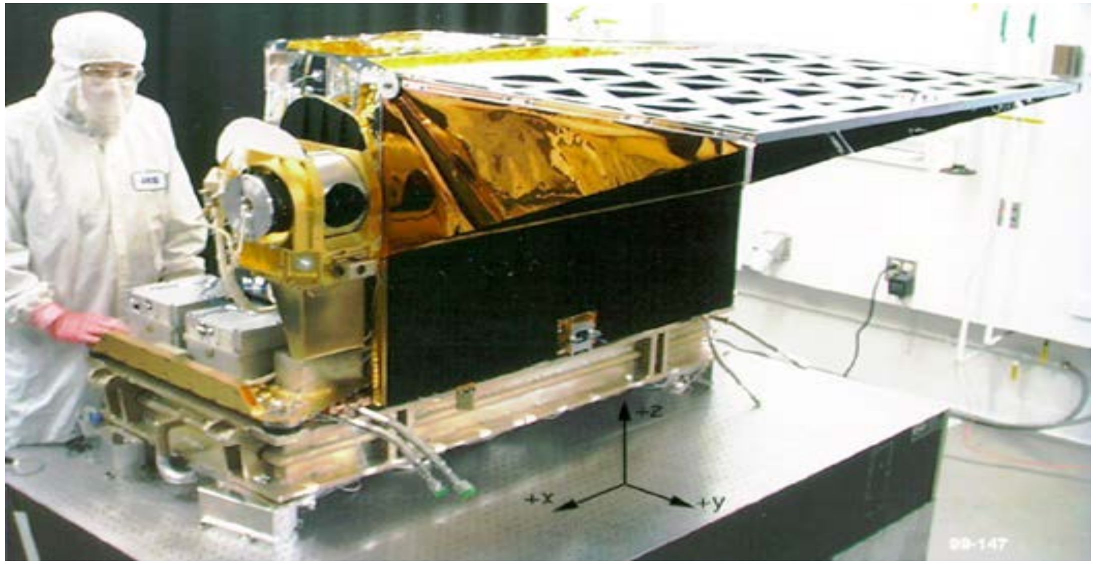
Earth Observation Technology: Traditional Approach



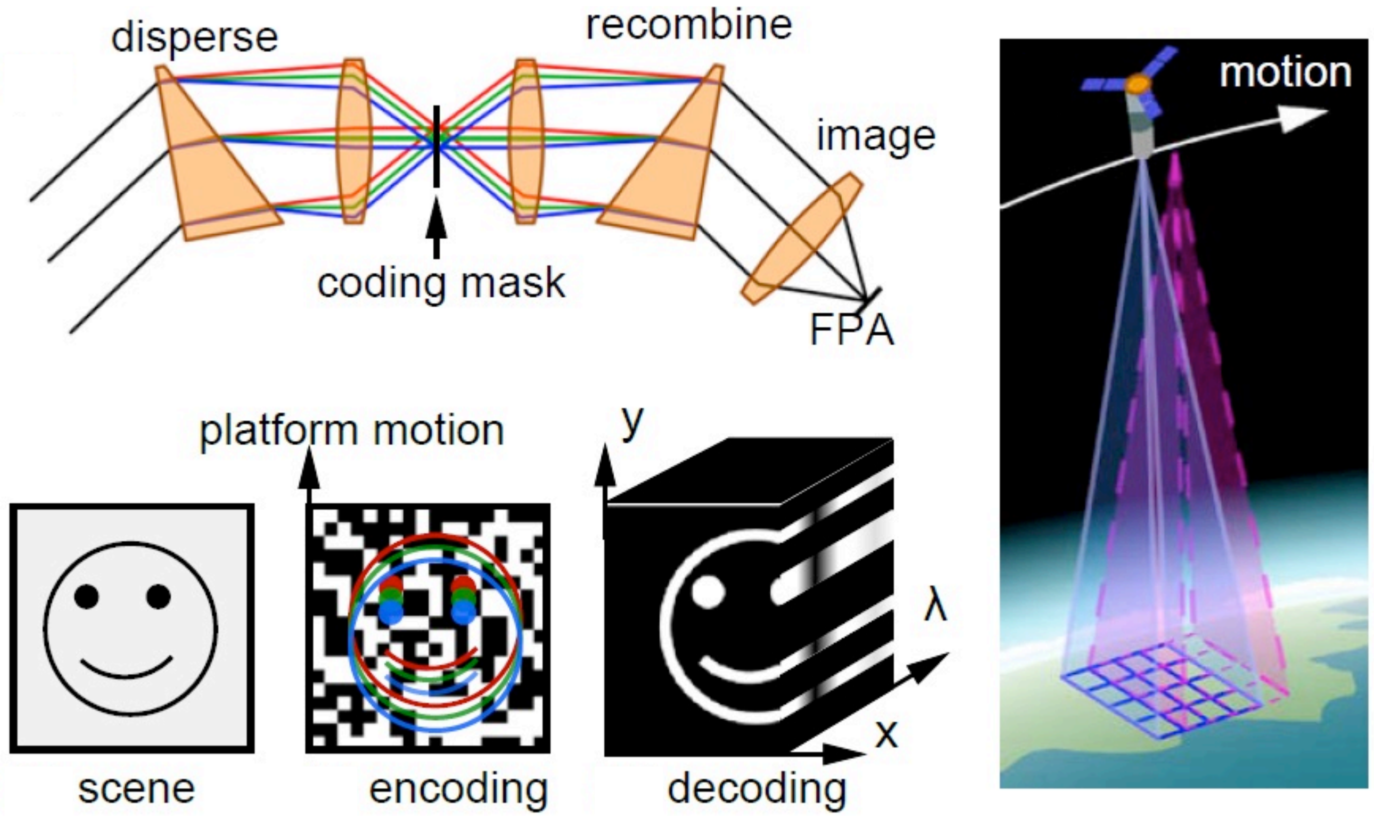
NASA's Aqua Satellite (2002-present)



NASA's Atmospheric Infrared Sounder (AIRS) instrument

- **Expensive (~$2B/satellite), and heavy (~2000 kg)**
- **Long development cycle (~10 yrs plus >10 yrs of operation)**
- **High consequences of failure**

Our Approach: Computational Reconfigurable Imaging Spectrometer (CRISP)

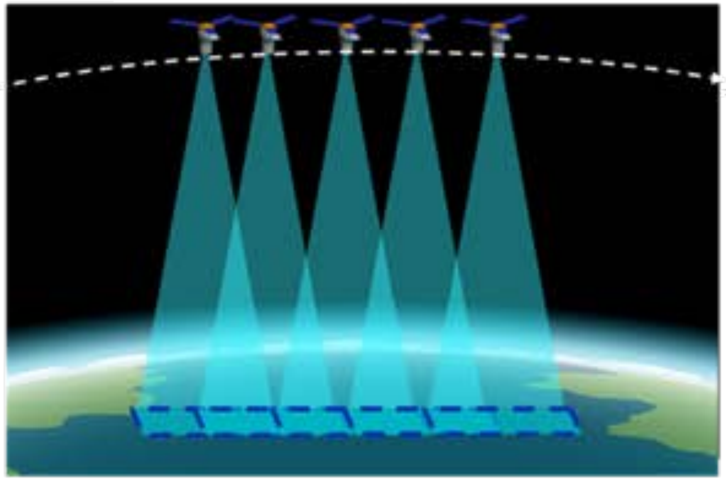


- **Uses static mask and scan/platform motion to encode spectral data cube**
- **Sensitivity advantages over traditional designs, enabling smaller infrared instruments that use uncooled thermal detectors**

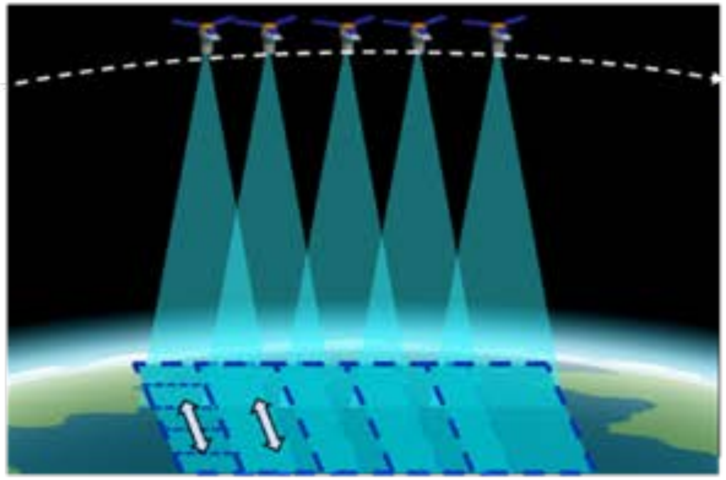
R. M. Sullenberger, A. B. Milstein, Y. Rachlin, S. Kaushik, C. M. Wynn, "Computational reconfigurable imaging spectrometer," Optics Express 25 (25), 31960-3196 (2017).

Proposed Operating Modes: Varying Area Coverage Rate

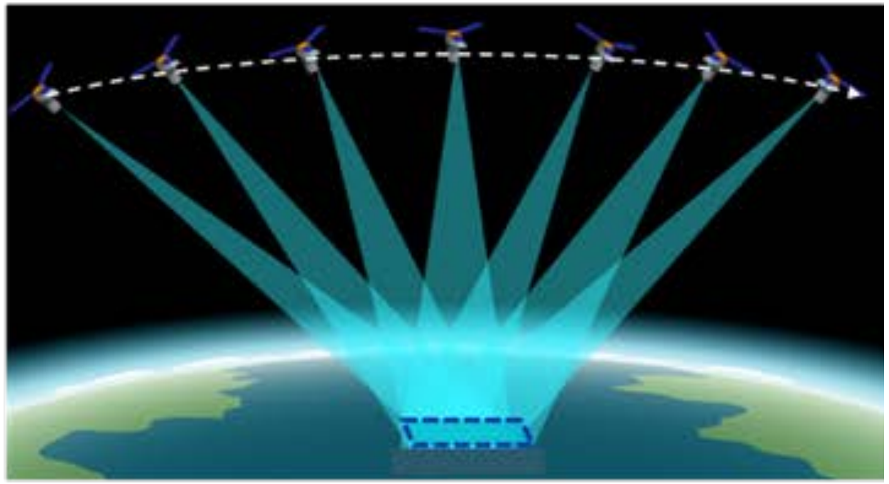
Drift Scan Mode



Wide Area Mode



Long Dwell Mode

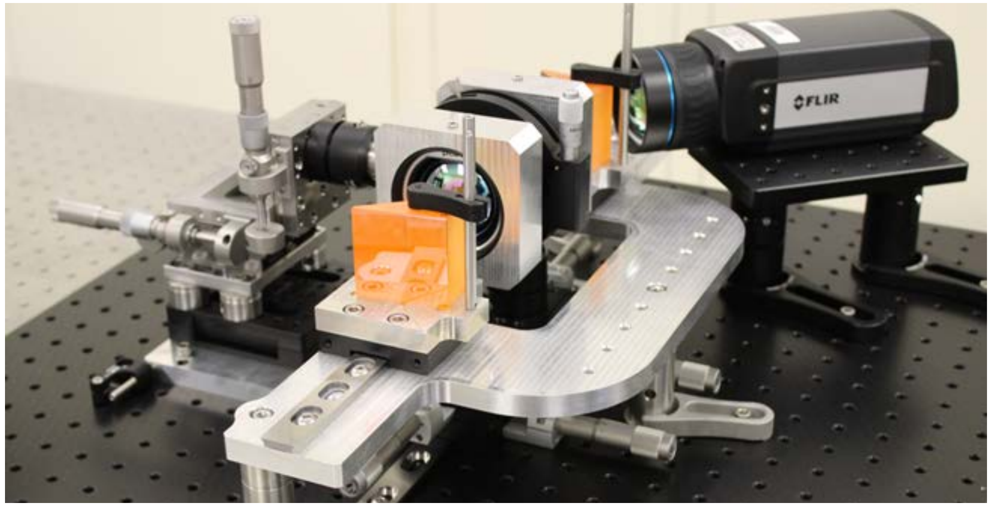


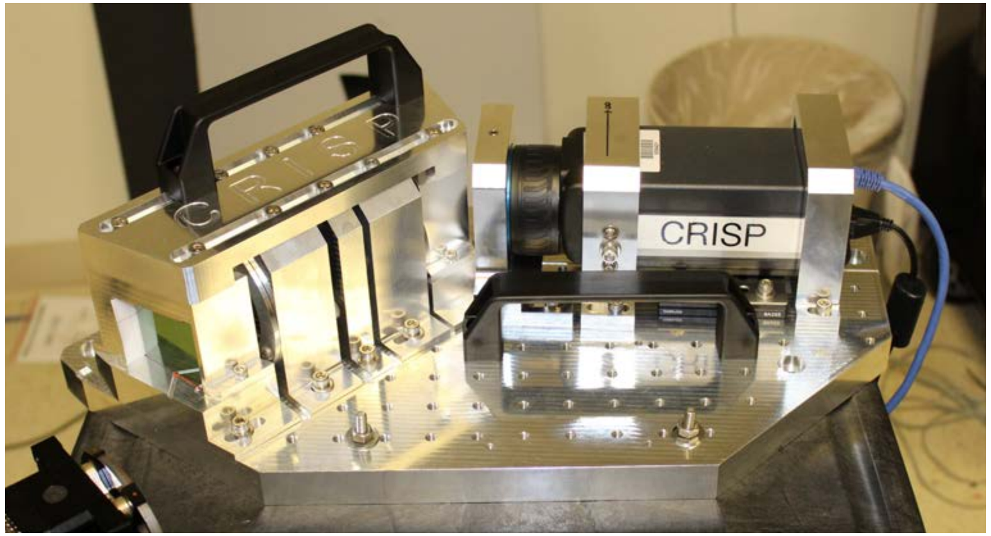
- **Example scenario: Cued Cubesat constellation**
  - **First sat identifies interesting phenomenon during wide area search**
  - **Second sat cued to look more closely with long-dwell mode**
- **CRISP concept allows flexible operation, based on mission-specific requirements for area coverage, spatial/spectral resolution, and sensitivity**

Breadboard Measurements

λ	7.7 μm – 14 μm (67 pixel dispersion extent)
$\Delta\lambda$	0.14 um resolvable
D	5 cm
FOV	~15°

- COTS f/1 camera lenses from FLIR
- Custom ZnSe prisms
- Custom designed mounts and baffles
- Uncooled microbolometer

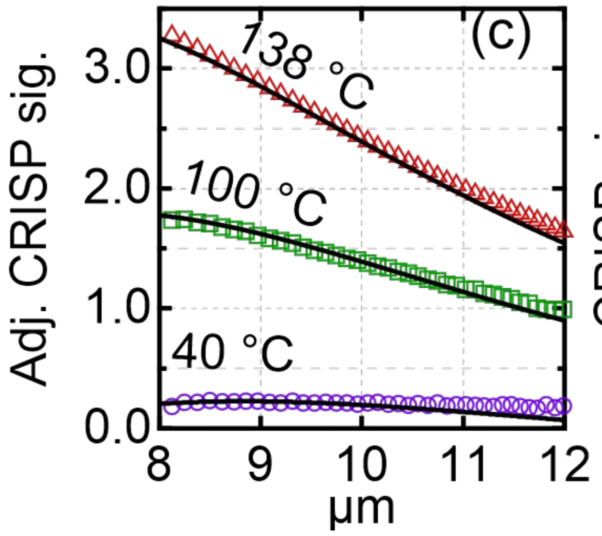




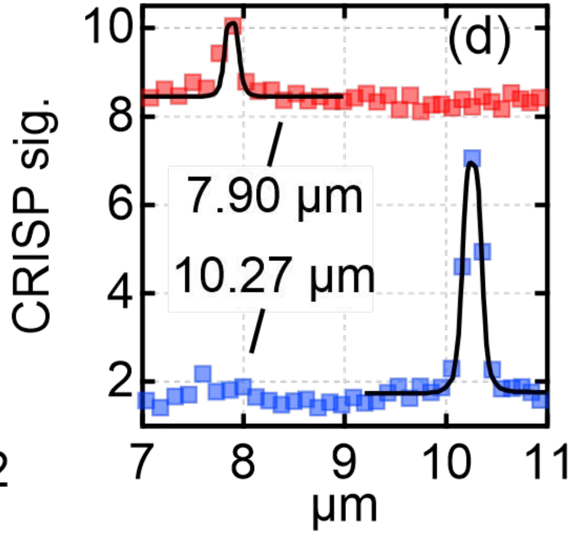
- Use breadboard to validate model predictions
- Ruggedized breadboard used in flight test

Lab Measurements: Spectra for Extended and Narrowband Sources, and Trace Gas

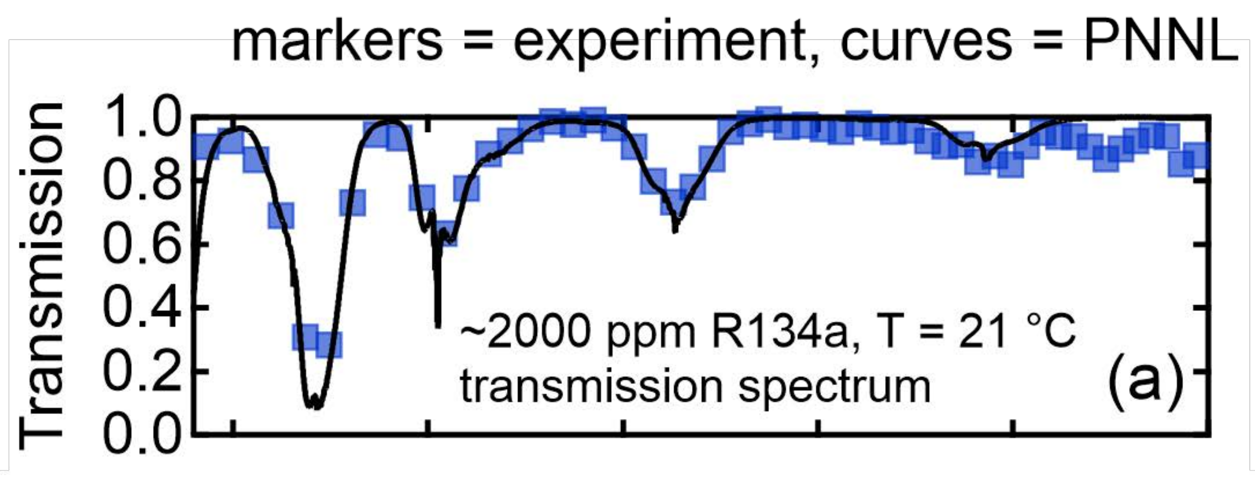
Blackbody Source



Narrowband Sources



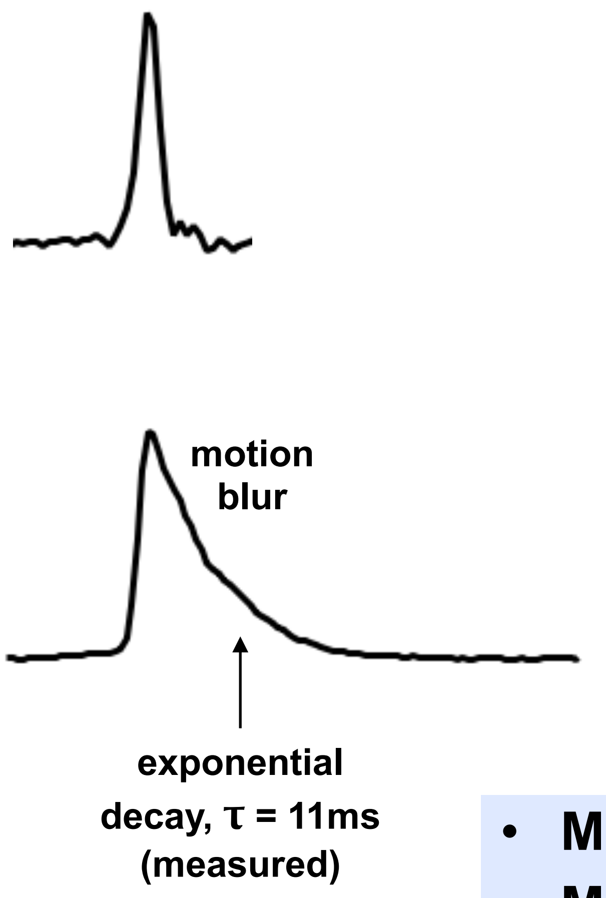
Transmission Through Absorbing Gas



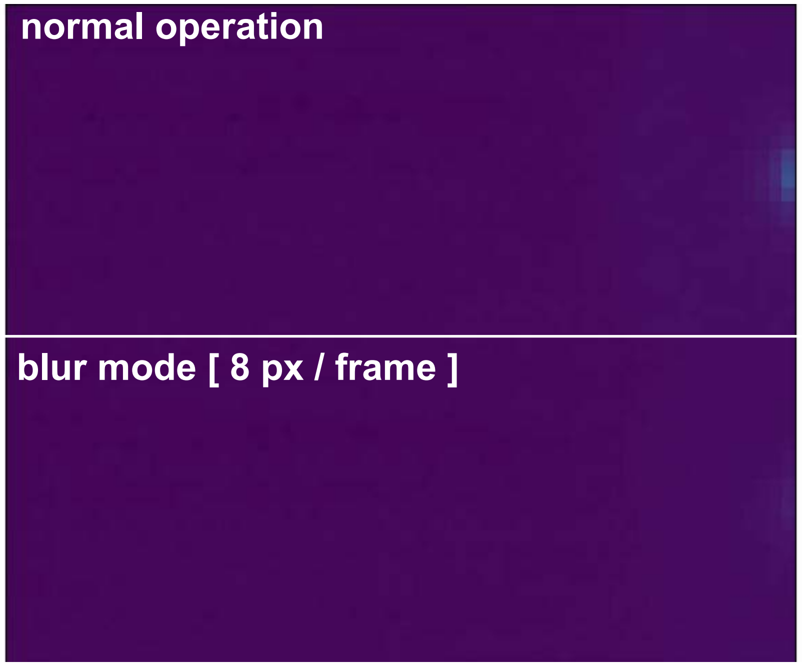
Breadboard measurements agree with predictions for broadband, narrowband, and trace gas absorption

Lab Measurements: Fast Scan with Motion Blur Removal

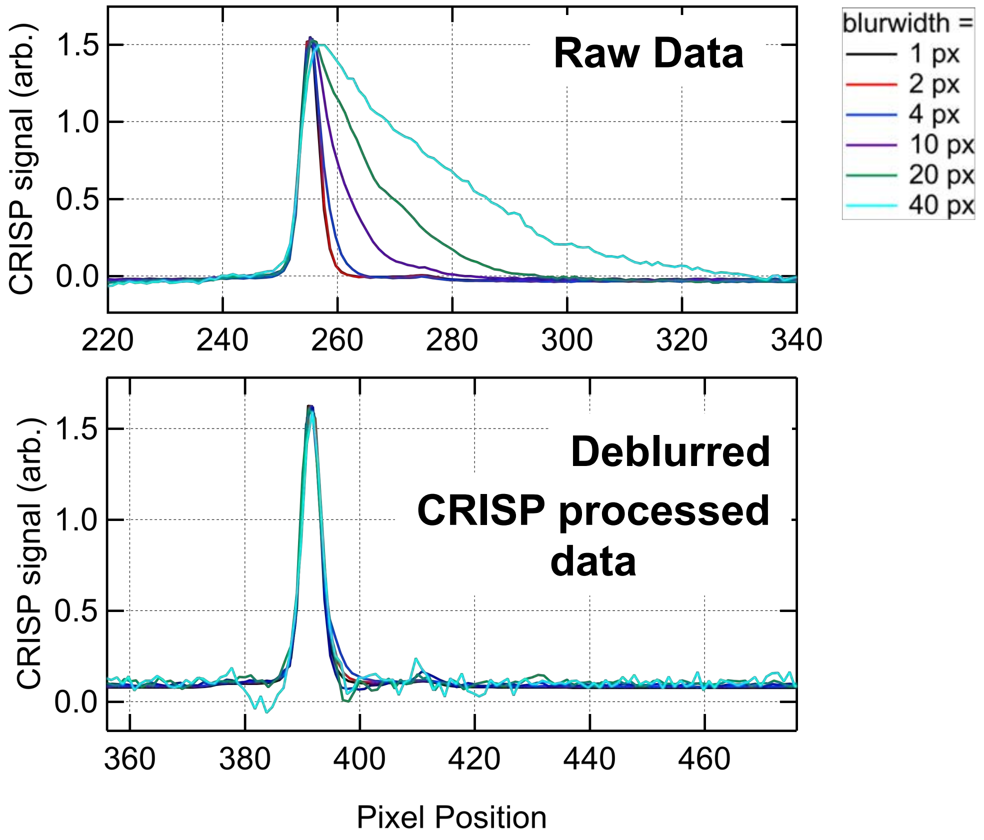
Point Source Motion Blur: Cross Section



Point Source Motion Blur: Raw Measurements

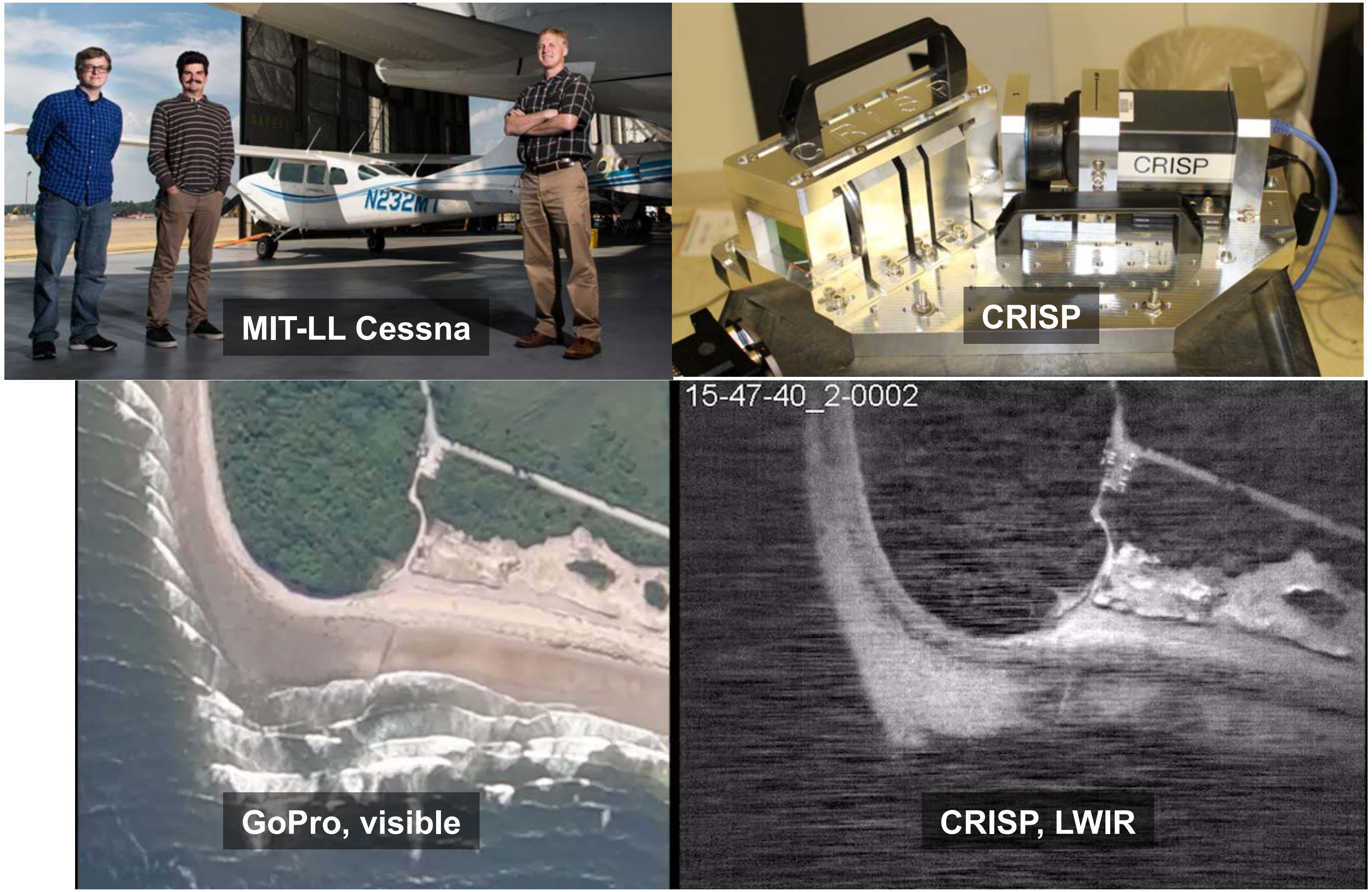


CRISP Inversion of Motion Blur



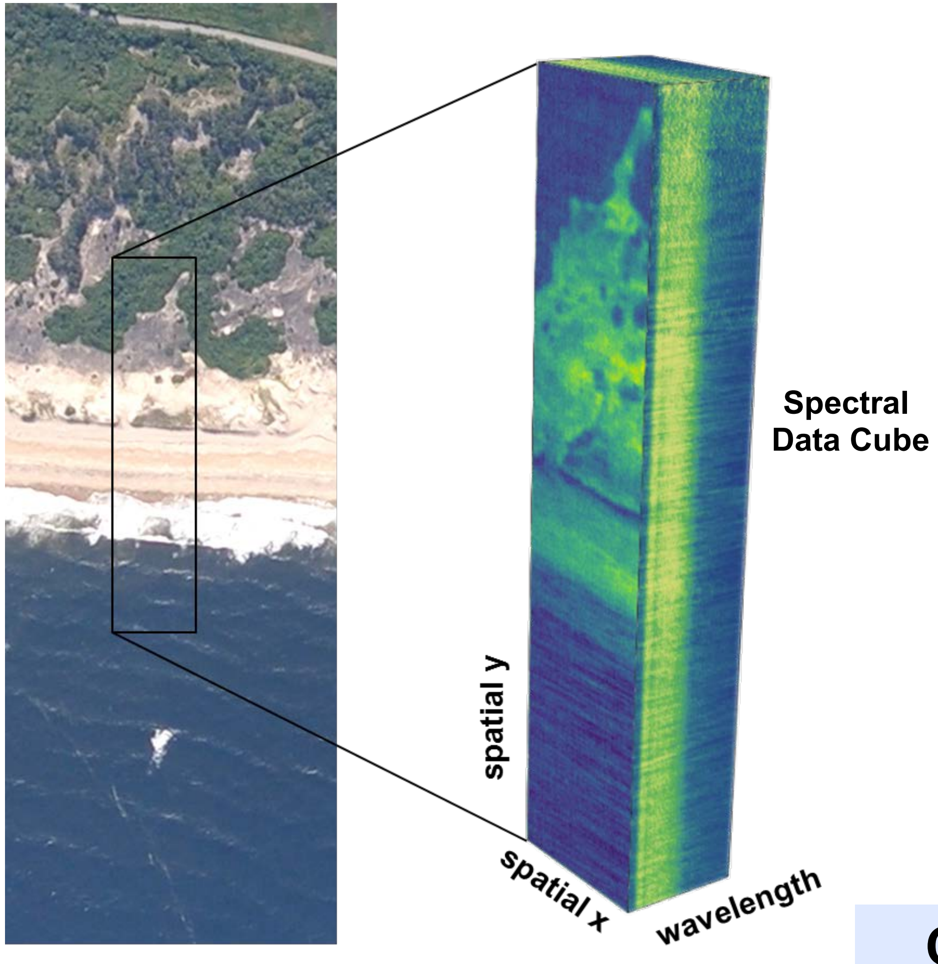
- Modulation from CRISP can be used to invert motion blur
- Maintains image quality even with low frame rates

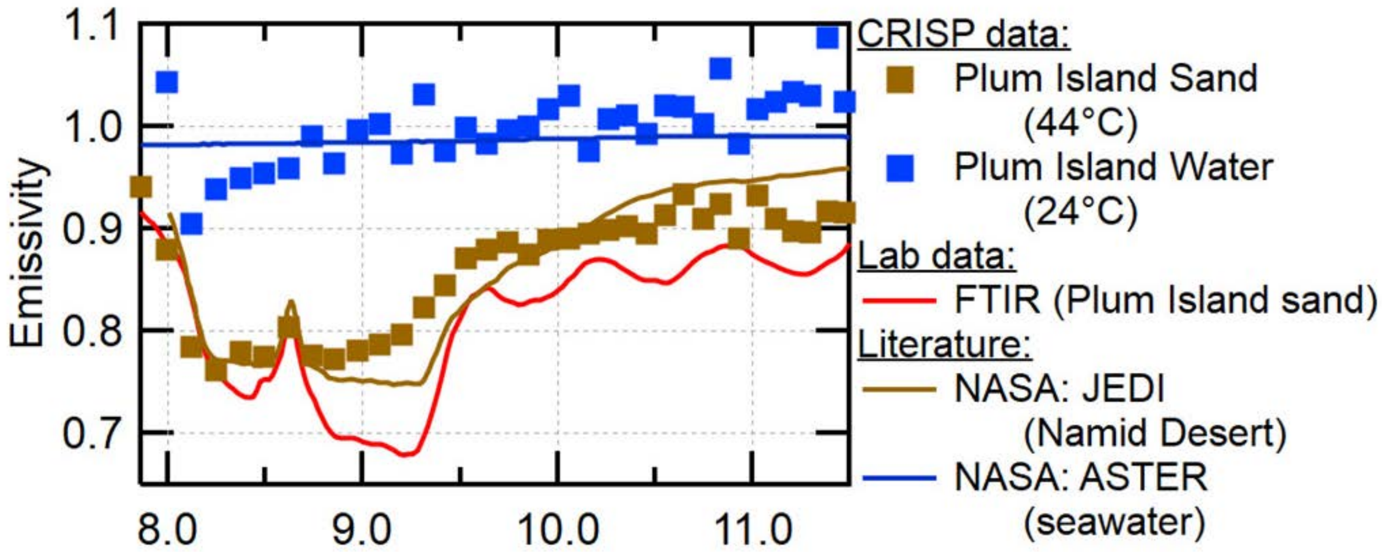
Flight Measurements: Initial Tests



CRISP demonstrated on real moving platform, with irregular motion

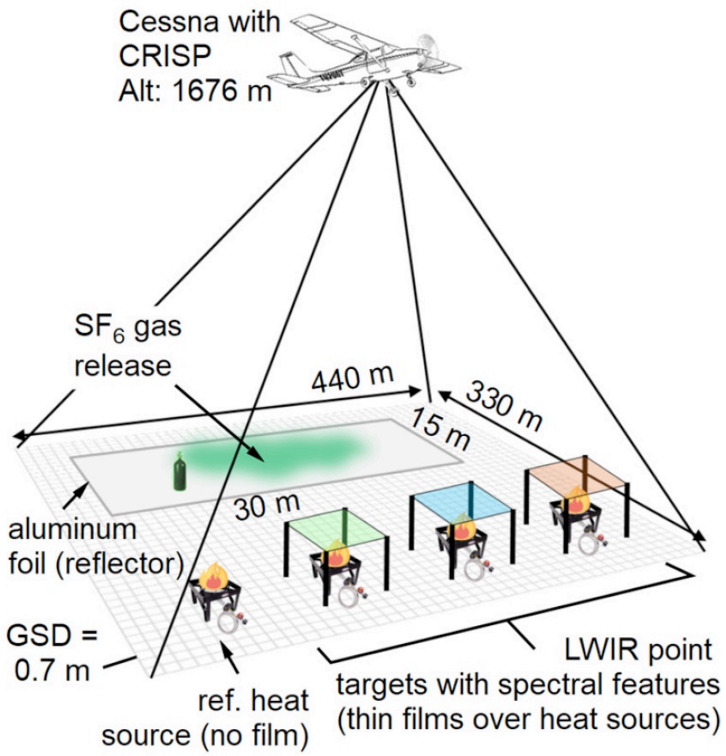
Flight Measurements: Coastal Crossing and TES

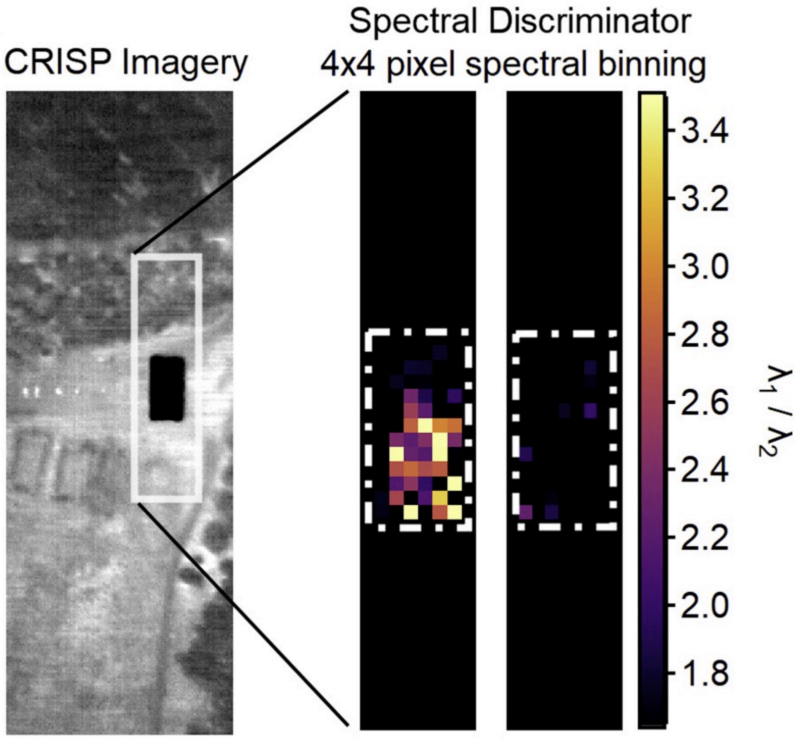


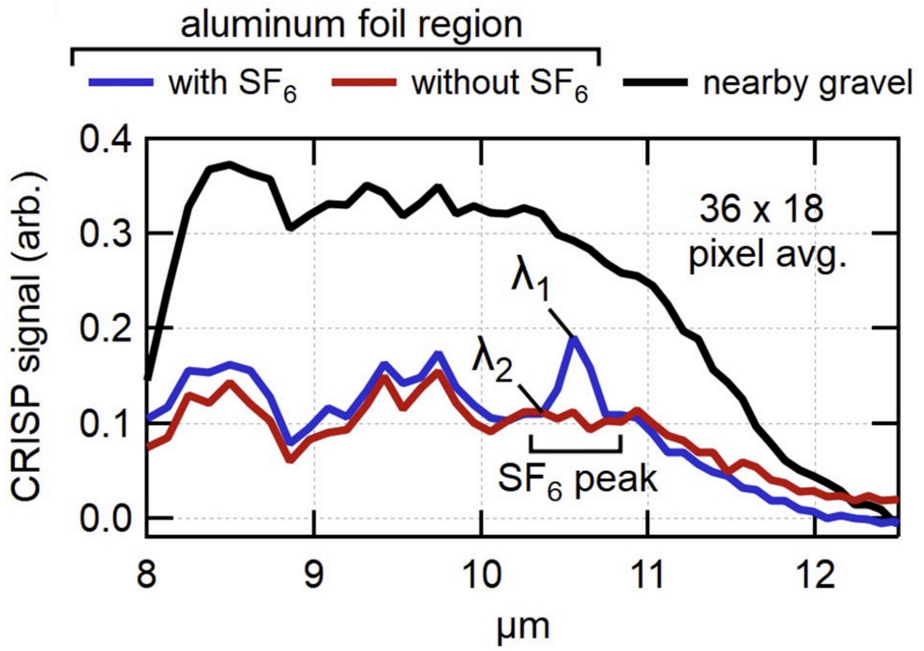


CRISP spectra agree with prediction for sand and water, and can support Temperature Emissivity Separation (TES)

Flight Measurements: Trace Gas Detection







CRISP successfully detected a trace gas release

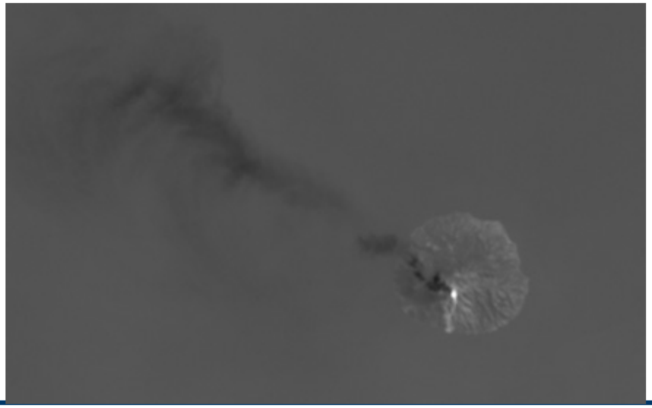
C. M. Wynn, J. Lessard, A. B. Milstein, P. Chapnik, Y. Rachlin, C. Smeaton, S. Leman, S. Kaushik, R. M. Sullenberger, “Flight tests of the computational reconfigurable imaging spectrometer,” Remote Sensing of Environment 239, 111621 (2020).

CRISP: Summary and Future Plans

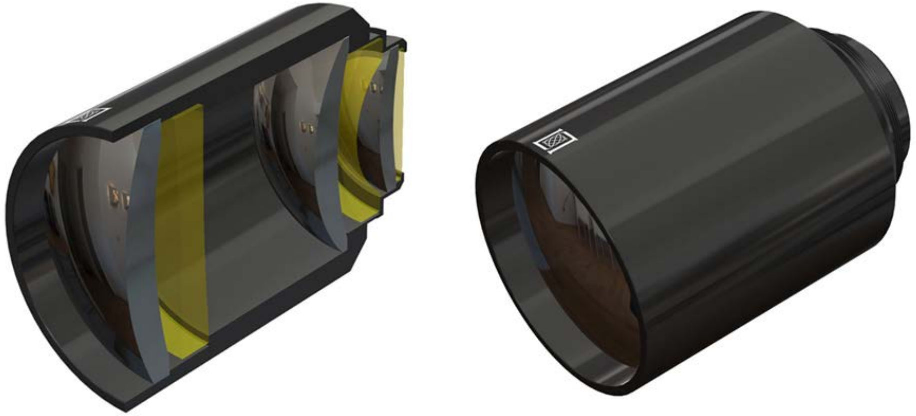
- We have validated key model predictions for CRISP in the lab and demonstrated spectral imaging in flight
- Current emphasis is on developing scan and spectral resolution modes and identifying performance limits
- We are currently proposing a brassboard instrument demo that would aim to meet future LandSat thermal IR band requirements
- Surface Biology and Geology and Planetary Boundary Layer mission concepts also being investigated

Landsat 8 Thermal Imagery

Paluweh volcano, Indonesia, April 2013

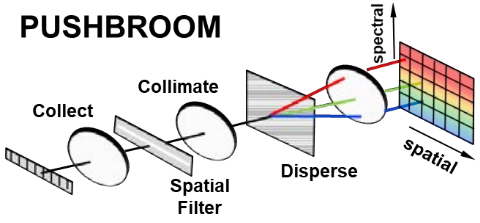


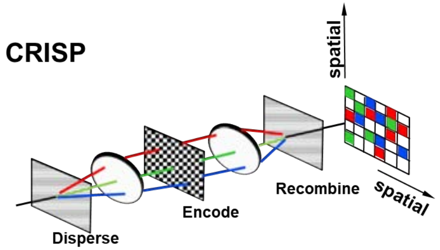
Proposed Brassboard Lens Barrel Design



BACKUP

SNR of CRISP vs. SNR of Conventional Slit-Based Spectrometers





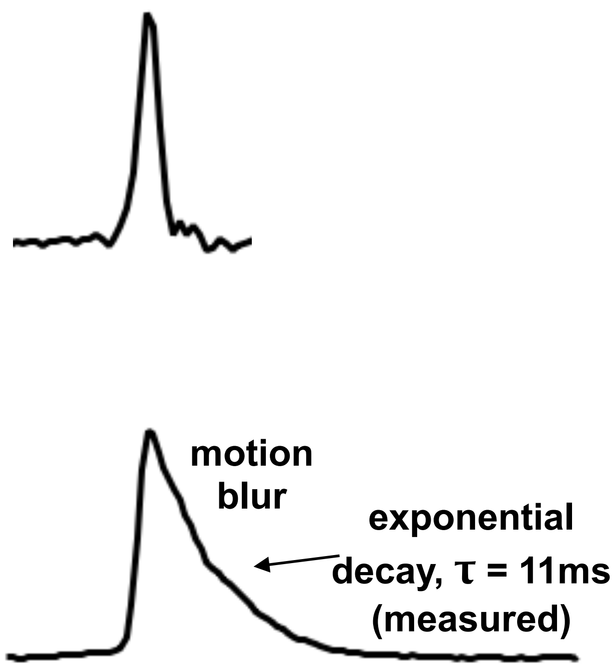
Example:
$M = 1920$ imager rows
$N_\lambda = 30$ wavelengths

	Slit-based system SNR scaling	CRISP SNR scaling	Rationale
Background-noise limited (e.g., visible CCD, cooled MCT)	1	$\sim\sqrt{M/2N_\lambda}$ Example*: $\sim 6\times$	CRISP is overdetermined: $M \gg N_\lambda$
Detector-noise limited (e.g., uncooled microbolometer)	1	$\sim\sqrt{M}/2$ Example*: $\sim 22\times$	Additional "multiplex" advantage when all λ measured at once

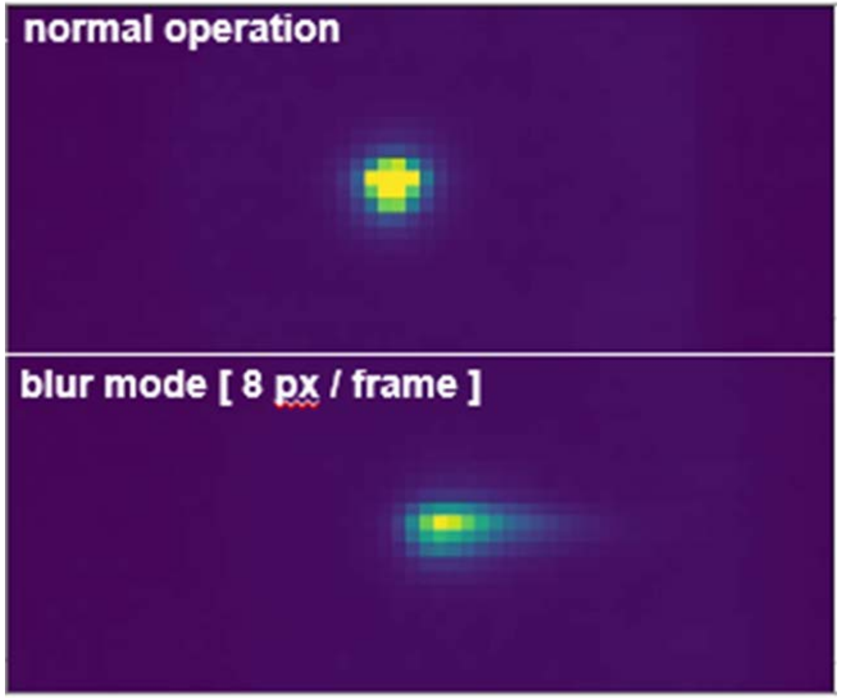
CRISP enables significant SNR improvement over conventional designs due to measurement count and wavelength multiplexing

Lab Measurements: Fast Scan with Motion Blur Removal

Point Source Motion Blur: Cross Section



Point Source Motion Blur: Raw Measurements



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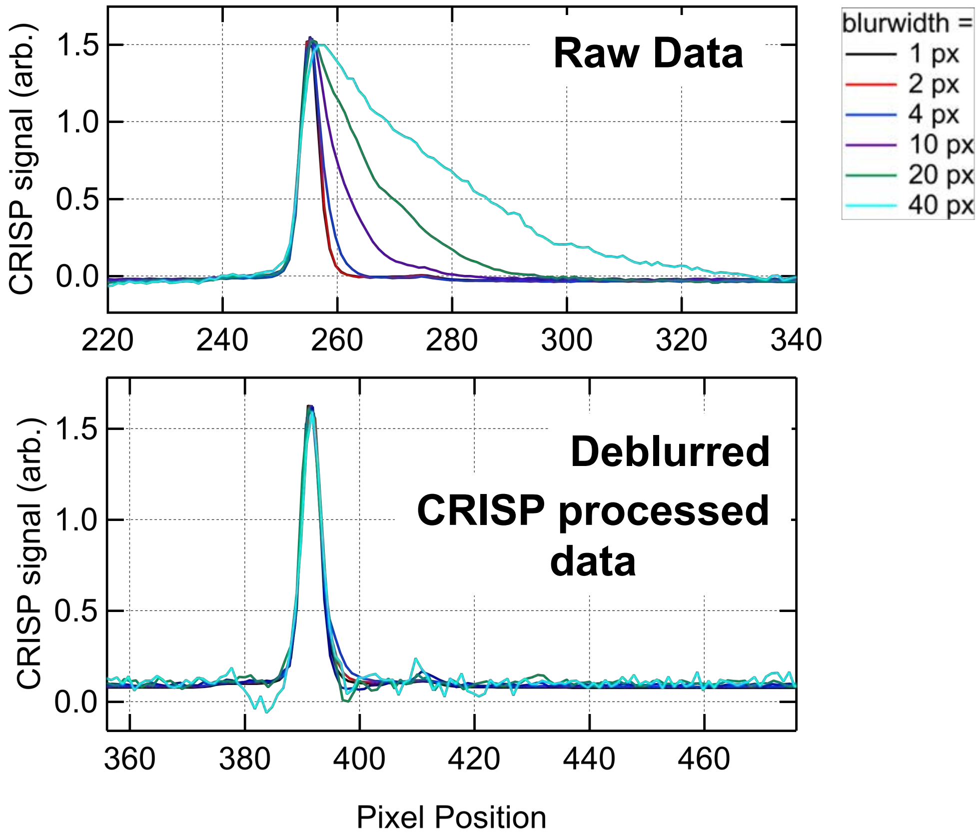
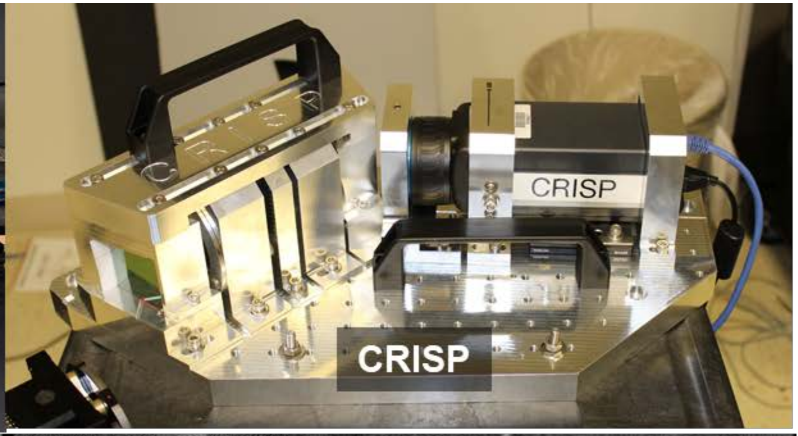


- Modulation from CRISP can be used to invert motion blur
- Maintains image quality even with very fast scans relative to frame rate

Flight Measurements: Initial Tests



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